The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes[1–3]

Alanna J Moshfegh, Donna G Rhodes, David J Baer, Theophile Murayi, John C Clemens, William V Rumpler, David R Paul, Rhonda S Sebastian, Kevin J Kuczynski, Linda A Ingwersen, Robert C Staples, and Linda E Cleveland

ABSTRACT

Background: The US Department of Agriculture Automated Multiple-Pass Method (AMPM) is used for collecting 24-h dietary recalls in What We Eat In America, the dietary interview component of the National Health and Nutrition Examination Survey. Because the data have important program and policy applications, it is essential that the validity of the method be tested.

Objective: The accuracy of the AMPM was evaluated by comparing reported energy intake (EI) with total energy expenditure (TEE) by using the doubly labeled water (DLW) technique.

Design: The 524 volunteers, aged 30–69 y, included an equal number of men and women recruited from the Washington, DC, area. Each subject was dosed with DLW on the first day of the 2-wk study period; three 24-h recalls were collected during the 2-wk period by using the AMPM. The first recall was conducted in person, and subsequent recalls were over the telephone.

Results: Overall, the subjects underreported EI by 11% compared with TEE. Normal-weight subjects [body mass index (in kg/m^2) < 25] underreported EI by <3%. By using a linear mixed model, 95% CIs were determined for the ratio of EI to TEE. Approximately 78% of men and 74% of women were classified as acceptable energy reporters (within 95% CI of EI:TEE). Both the percentage by which energy was underreported and the percentage of subjects classified as low energy reporters (<95% CI of EI:TEE) were highest for subjects classified as obese (body mass index > 30).

Conclusions: Although the AMPM accurately reported EIs in normal-weight subjects, research is warranted to enhance its accuracy in overweight and obese persons. *Am J Clin Nutr* 2008;88:324–32.

INTRODUCTION

What is the most effective way to collect a complete 24-h dietary recall? Finding the answer to that question has been a major focus of research by the US Department of Agriculture (USDA) Agricultural Research Service (ARS), and studies to enhance and improve the 24-h recall led to the development of the USDA's Multiple-Pass Method in 1999. This is a 5-step dietary interview that includes multiple passes through the 24 h of the previous day, during which respondents receive cues to help them remember and describe foods they consumed (1, 2). Initially, a pencil-and-paper version of the method was used in observational validation studies in women (3) and men (4) and also in the Observing Protein and Energy Nutrition (OPEN) study (5), a large validation study using biomarkers.

Since then, a computer-assisted version of the 5-step method, the Automated Multiple-Pass Method (AMPM), was developed. The AMPM navigates the interviewer through the recall, posing standardized questions and providing response options for different foods and beverages. It has been used since 2002 to collect dietary recalls in What We Eat in America (WWEIA), the dietary interview component of the National Health and Nutrition Examination Survey (NHANES) (6). The result of integrating the dietary data collection activities of the Continuing Survey of Food Intakes of Individuals (CSFII) and the NHANES, the national survey WWEIA collects 2 d of dietary data on ≈5000 participants each year. Data from the WWEIA survey are used in developing nutrition- and food-related regulations, programs, and policies as well as dietary standards and recommendations for the federal government (7).

Despite the importance of surveying food intake, the accuracy of dietary intake data remains a problem (8, 9), and researchers have called for dietary surveys to provide independent evidence of their validity (10). In recent studies using the AMPM, mean energy intake (EI) was accurately reported for small groups of normal-weight men (11) and women (12).

The purpose of the present study was to evaluate, in a large and more diverse sample, the extent of EI misreporting. Analyses compared reported EI with total energy expenditure (TEE) by using the doubly labeled water (DLW) technique, which has been shown to provide an accurate measure of the TEE in free-living subjects (13, 14). Information on the nature and magnitude of reporting error is critical to the interpretation of national survey data and the targeting of future research needs.

SUBJECTS AND METHODS

Subjects and recruitment

The study cohort consisted of 525 volunteers 30–69 y of age residing in the greater Washington, DC, metropolitan area.

Recruitment procedures included advertisements in local newspapers and on ARS websites; announcements sent to employees of USDA (Beltsville, MD), local industries, and offices; and the use of a Beltsville Human Nutrition Research Center (BHNRC) database of persons known to be interested in participating in human studies. After attendance at an informational meeting, interested applicants provided written informed consent. Because of the requirements of informed consent, details about all study procedures were explained; however, there was no reference to a validation study. Applicants were told that the purpose of the research project was to learn about the foods they ate and to ascertain the number of calories they burned each day.

Potential subjects completed 2 medical screening visits that included measurement of height, weight, and blood pressure; a medical history; and evaluation of standard laboratory analyses of fasting blood and urine samples by a cooperating physician. All eligible subjects were in basic good health, were weight stable, and were not actively pursuing a weight-loss regimen or taking medications known to affect food intake, appetite, or water balance. Pregnant and lactating females, persons with diabetes, and nutrition professionals were excluded. Recruitment efforts were targeted to adults aged 30–69 y; however, from the pool of eligible participants, subjects were selected to yield an equal number of males and females and to include a range of ages and body mass index (BMI). To maintain a usual background level of the measured isotopes (for determination of TEE) obtained from the water supply, subjects were also selected on the basis of their ability to remain in the local area before and during their data collection period.

The Johns Hopkins University Bloomberg School of Public Health Committee on Human Research approved the study protocol. Subjects were compensated $325 to offset their time and effort in completing the study.

Study design

This study was conducted at the BHNRC Human Study Facility (HSF) between July 2002 and June 2004. Data collection was conducted in 5 cohorts for ≈7 wk each; the periods between collections in cohorts was used for recruitment and screening of potential subjects. Each subject entered the study for a 2-wk period of free-living activities, and data were collected during 4 visits to BHNRC-HSF plus 2 telephone interviews. In addition, subjects attended a mandatory scheduling visit that occurred ≥3–4 d before the actual start date. The purpose of this visit was to verify eligibility for participation and to schedule times and dates for all subsequent visits. Body weight, taken at this visit and compared with the weight recorded at screening, was used as an estimate of weight stability.

During the study period, three 24-h dietary recall interviews were conducted; the first was administered in person during center visit 1 (CV1). Before the interview, subjects received a dose of DLW for the measurement of TEE.

The second and third dietary recalls were scheduled 5–6 and 10–11 d, respectively, after CV1. Both interviews were conducted by telephone in the subject's home at a scheduled time. Spot urine samples to be used for TEE determination were collected daily during the 2-wk study period. Subjects were instructed to collect (using the provided containers) the second (or later) urine void of the day and to record the date and time. At CV2 and CV3 to the BHNRC, subjects returned any spot urine samples collected at home and also provided that day's spot urine

sample. These visits allowed a staff member to verify the date and time of the spot urine samples to ensure accurate recording.

At CV4, scheduled 14 d after CV1, subjects provided a final spot urine specimen, which completed the DLW protocol. Subjects were instructed to fast for 12 h and to avoid strenuous activity on the day before the visit. Resting energy expenditure (REE) was measured, and subjects provided a blood specimen (for use in future analysis). To assess any weight change during the 2-wk study period, body weight was measured at CV1 and CV4. With the subject wearing a standardized hospital scrub set and no shoes, weight was measured to the nearest 0.01 kg by using the same electronic balance each time. Height was measured at CV1 to the nearest 0.1 cm with a wall-mounted stadiometer. BMI was defined as CV1 wt (kg)/height^2 (m).

During the study period, subjects were instructed to follow their usual eating and activity patterns. Reminder sheets listing study procedures and appointment times for telephone interviews and center visits were provided at the conclusion of each visit. Subjects also received reminder telephone calls before each visit.

Energy intake assessment

The 24-h dietary recalls were conducted by using the AMPM, which uses multiple memory cues with standardized wording to elicit recall of all possible foods. The 5 steps of this method are detailed in **Table 1**. Subjects were interviewed 3 times with the AMPM; the first interview was conducted in-person, and subsequent recalls were conducted by telephone. By study design, interviews were distributed fairly equally across the days of the week, and subjects were interviewed on at least one weekend day

TABLE 1
Outline of the 5 steps in the US Department of Agriculture Automated Multiple-Pass Method (AMPM) for collecting 24-h dietary recalls

Step	Purpose
1. Quick list	To collect a list of foods consumed by the respondent in a 24-h period on the day before the interview. Gives cues to think about the day's events to help remember the foods eaten. Respondent uses own recall strategies.
2. Forgotten foods list	To elicit additional recall of foods by focusing respondent's attention on 9 categories of foods that are often forgotten: nonalcoholic beverages, alcoholic beverages, sweets, savory snacks, fruit, vegetables, cheeses, breads and rolls, and any other foods.
3. Time and occasion	To collect information on the time at which the respondent ate each food and the name of the eating occasion. Sorts foods into chronological order and groups them by eating occasion for the Detail and review pass.
4. Detail and review	To collect a detailed description of each food reported (including additions to the food), amount eaten, its source (eg, store or restaurant), and whether it was eaten at home. To review each eating occasion and the intervals between eating occasions to elicit additional recall.
5. Final probe	To provide a final opportunity to recall foods. Gives cues about nonsalient situations when foods may be eaten and easily forgotten. Encourages reporting of small amounts of food that may have been regarded as not worth mentioning.

and one weekday. Intakes were obtained during all seasons of the year.

Because the AMPM is the instrument used to collect data in WWEIA, the environment in which subjects were interviewed replicated, to the extent possible, that used for the national survey. The portion size estimation aids used in the interviews were the same as those used in WWEIA (15). During the in-person interview, subjects were referred to 47 different 3-dimensional models consisting of glasses, mugs, bowls, bean bags, circles, thickness sticks, and beverage cartons. Also available were the following: a 12-in ruler, measuring cups and spoons, metal household spoons, cards depicting pats and spreads, a grid, wedges, geometric shapes, and diagrams of chicken pieces.

At the end of CV1, subjects were given a set of measuring guides, including the USDA Food Model Booklet (FMB) (16), measuring cups and spoons, metal household spoons, and a 12-in ruler, for use during the telephone interviews,. The FMB contains life-size drawings of glasses, mugs, bowls, mounds, pats and spreads, circles, and thickness blocks that are the same size as the models used in the in-person interview, plus a grid, wedges, geometric shapes, and diagrams of chicken pieces.

Quality control of the interviewing process was conducted over the course of this study. Dietary interviewers were monitored on ≈13% of interview days for both in-person and telephone recalls. All interviewers either were educated in nutrition or health studies or they had experience conducting nutrition research. In addition, they completed 32 h of formal training on the AMPM and refresher training before the start of each cohort.

Dietary recalls were processed by using USDA SURVEY-NET software (version 3.15) (1). The USDA Food and Nutrient Database for Dietary Studies [FNDDS; version 1.0 (17)] was used to convert food consumed into gram amounts and to determine nutrient values. During dietary processing, various quality-assurance procedures were conducted to ensure the quality of the data (18).

Measurement of total energy expenditure

Daily TEE was measured by using the DLW method. Scientists at BHNRC's Food Components and Health Laboratory (formerly the Diet and Human Performance Laboratory) provided technical expertise and performed all analyses and calculations used in the determination of TEE.

At CV1, subjects drank a previously mixed dose of DLW, containing ≈0.10 g H_2O/kg body wt and 0.08 g $H_2^{18}O$/kg body wt. To ensure that the full dose was consumed, the dose bottle was then rinsed 3 times with a total of 100 mL deionized water, which was also consumed. A 24-h urine sample collected on the previous day was used to measure background isotope enrichments. Urine samples were collected daily for 14 d; 6 of the samples, including the 3 collected at center visits were used for analysis.

Isotopic enrichment of urine samples was measured by using continuous-flow, isotope ratio–mass spectroscopy (Europa Scientific Hydra, Crewe, United Kingdom). The spectrometer was calibrated before analysis of each subject's samples, which were analyzed in triplicate. For analysis of ^2H, a platinum catalyst was added to a 1-mL sample in a glass tube, and the air was evacuated; samples equilibrated for 72 h before analysis. For analysis of oxygen, a 1-mL sample was placed in a tube, and air was evacuated and replaced with 5% CO_2 and 95% N_2 gas. Standards for both isotopes were prepared and calibrated to Vienna Standard

Mean Ocean Water (SRM#8535; National Institute of Standards and Technology, Gaithersburg, MD).

Isotope kinetics was determined by using a multipoint calculation technique (19). The ^2H and ^{18}O zero-time intercepts and clearance rates (k_h and k_o) were calculated by using least-squares linear regression on the natural logarithm of isotope concentration as a function of elapsed time from dose administration. The zero-time intercepts were used to determine the isotope pool sizes at the time of the dose. Total body water (TBW) was calculated as the average of the ^2H and ^{18}O dilution spaces calculated from the intercept and corrected for 4% and 0.7% in vivo exchange, respectively. TEE was estimated by using the following equation of Weber et al (20):

$$TEE = \{[TBW/2.078][1.007k_o - 1.041k_h] - [0.0246$$
$$\times 1.05TBW(1.007k_o - 1.041k_h)]\} \times 22.4 \times 5.6535 \quad (1)$$

The energy equivalent of carbon dioxide (5.6535) was based on an assumed respiratory quotient (RQ) of 0.86. To minimize the effect of analytic variability, all samples for an individual subject were analyzed at the same time by using the same standard curve. The accuracy of DLW in our laboratory was determined to be 1.6 ± 2.6% (21)

The within-subject variability in the DLW measurement for this study was obtained by re-dosing a subset of subjects. The same procedures were followed for the second measurement of TEE in 42 weight-stable subjects. The change in body weight in each of the 22 males and 20 females, between the original and replicate TEE measurements (an average span of 66 wk), was <5%.

Resting energy expenditure

By following a standardized protocol, resting energy expenditure (REE) measurements were conducted at CV4 between 0630 and 0930. Subjects were instructed to fast for 12 h and to refrain on the day before their visit from strenuous activity that was not part of their regular routine. In addition, subjects were asked to keep activities to a minimum and to avoid any exercise during the waking hours before arrival. Before commencement of the measurements, subjects sat quietly for ≥15 min. Measurements were taken while subjects were in a supine position, and they were instructed to remain awake and completely still during the measurement.

REE was measured by indirect calorimetry with the use of a clear plastic canopy (Beckman Instruments, Inc, Anaheim, CA) developed by Kinney et al (22). The analytic system was described previously (23), and updated electronics and gas analyzers were used. A 30-min measurement protocol was followed; the first 10 min and the last 2 min of data were discarded, along with periods of movement by the subject. With the use of a software package developed at BHNRC, estimates of REE per 24 h were calculated according to the formula of de Weir (24). Gas analyzers were set to zero with a stream of 100% N_2 gas before a daily session of REE measurements, and they were calibrated with a gas mixture of ≈19% O_2 and 1% CO_2 before each individual REE measurement.

To confirm the accuracy of the analytic system, ethanol combustion tests were conducted before and after a series of REE measurement sessions. The average recovery of dioxide and carbon dioxide was 101.6% and 99.9%, respectively. The results of the alcohol combustions were used to normalize the REE

values and to account for potential differences due to the length of data collection and the use of 2 measurement stations and different tanks of calibration gas. The calibration of the mass flow meters also was periodically checked with a dry gas meter (American Meter Co, Erie, PA). Overall, the within-subject ($n =$ 24) CV was $3.5 \pm 3.6\%$ for measurements conducted 2 wk apart.

Statistical analysis

Statistical analyses were performed with PC-SAS software (version 9.1; SAS Institute Inc, Cary NC). Means and SDs were calculated to describe subject characteristics. Because EI and TEE data were negatively skewed, all energy measurements were log-transformed to improve distribution toward normality. To account for serial correlations between individual subject 24-h dietary recalls, the sample within-subject variance and SD were estimated from a linear mixed model of EI and TEE for each 24-h dietary recall by using the SAS PROC MIXED procedure. Within sex and BMI categories, 24-h recall subgroup variance and SDs were estimated from the least-squares mean ($\pm$ SE) within the subgroup linear mixed model. Missing values were assumed to be missing at random, and 95% CIs were calculated by using the maximum likelihood method.

Definition of misreporters and accurate reporters

Accurate reporting was inferred wherever log(EI/TEE) values fell within 95% CI around the expected mean of zero. Values above or below the 95% CI were taken to indicate overreporting or underreporting, respectively.

The sample SD of log(EI/TEE) is written according to the following equation:

$$\sigma_Y = \sqrt{\sigma_{F/k}^2 + \sigma_{M/m}^2} \qquad (2)$$

where *F*, *M* and *Y* are log(EI), log(TEE), and log(EI/TEE), respectively. The 95% CI for an AER is written as

$$95\% \text{ CI} = -1.96\sqrt{\sigma_{F/k}^2 + \sigma_{M/m}^2}, \ 1.96\sqrt{\sigma_{F/k}^2 + \sigma_{M/m}^2} \quad (3)$$

where σ_F^2 and σ_M^2 denote the within-person variation for reported EI and measured TEE, respectively.

Assuming independence for 24-h recalls and TEE measurements, σ_F^2 and σ_M^2 can be estimated as two-thirds of the EI sample variance of $(1/2\log_{f1} + 1/2\log_{f2} - \log_{f3})$, and half of the TEE sample variance of $(\log_{g1} - \log_{g2})$, respectively, in a design with 3 EI ($k = 3$) and 2 TEE measurements per subject (25).

The within-subject CV for EI was 22.6% ($n = 513$). Expressed as a percentage of the sample mean average EI, the mean absolute error was 17.7% The estimated σ_M^2 for the AMPM validation study with a single measurement of TEE ($m = 1$) per subject was derived from the CV for TEE (12.6%) calculated from the subset of subjects who had replicated TEE measurements ($n = 42$). From the SD on the log scale (lgstdev), the CV on the original scale is given by the following formula:

$$\text{CV} = 100 \times [\exp(\text{lgstdev}) - 1] \qquad (4)$$

as described by Snedecor and Cochran (26).

When separated by BMI classification, CVs for TEE of 12.1%, 12.4%, and 15.5% were calculated separately for normal-weight ($n = 19$), overweight ($n = 14$), and obese ($n = 9$) subjects, respectively. Bartlett's test of variance homogeneity was not

significant; consequently, a constant value for $\sigma^2 M$ was assumed. A visual presentation of the replicated TEE plotted against TEE for the 42 weight-stable subjects is given in **Figure 1**.

RESULTS

After attending a study information meeting, 898 persons provided written informed consent and were scheduled for medical screening visits. Of the 792 who completed both screening visits, 657 (83%) were eligible to participate in the AMPM validation study. All but 1 of the 525 subjects who were dosed with DLW completed the study. Because no usable data were obtained from that subject, 524 subjects were included in the study sample.

General characteristics of the study population are presented in **Table 2**. The subjects, who were predominantly non-Hispanic white, were distributed evenly by sex and approximately by age. Only 8% of subjects had not attended college. Approximately 21% of the subjects (both sexes) were obese [BMI (in kg/m^2) > 30]. More females (48%) than males (36%) were considered normal-weight. Only 5% of the men and 6% of the women were current smokers.

TEE measures for a total of 27 subjects were excluded; 9 of those subjects were dropped because of protocol noncompliance. Measures for 18 subjects were eliminated because of abnormal values for isotope elimination rates. A repeat calculation confirmed the initial values of these 18 subjects and suggested that the samples had been contaminated or mislabeled.

EI data were usable for 519 subjects, all but 6 of whom had three 24-h recalls. Therefore, $\approx$99% of the possible 1572 dietary intakes were included in the analysis. Daily intake data were excluded from the 22 recalls because of noncompliance, reported illness, or a language barrier.

The distribution of 24-h recalls by the day of the week is shown in **Table 3**. For both males and females, dietary recalls were distributed fairly equally across all 7 days of the week. The percentage for each day of the week ranged from 13% to 16% of the total number of recalls.

The geometric means, medians, and 25th and 75th percentiles for EIs energy as measured by DLW and as self-reported from the
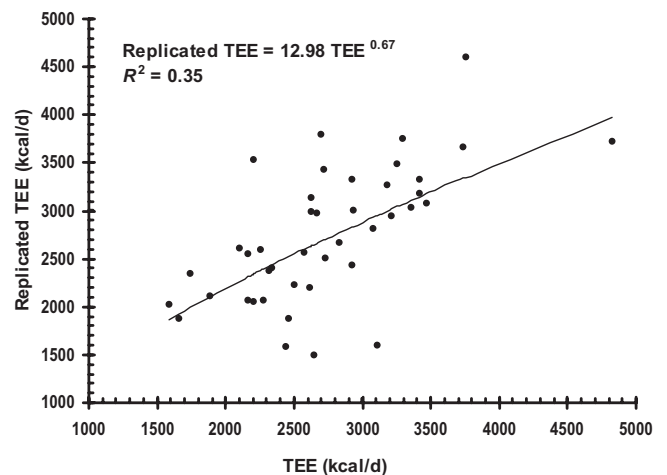

FIGURE 1. Replicated total energy expenditure (TEE) against TEE for 42 weight-stable subjects. The replicated TEE was measured 66 wk later on average. The solid line represents a back-transformation of a linear fit to the logTEE data points.

TABLE 2
Demographic characteristics of the total study sample

	Men (*n* = 262)	Women (*n* = 262)
	%	%
Age (y)		
30–39	21	23
40–49	28	26
50–59	26	29
60–70	24	21
Race-ethnicity		
Non-Hispanic white	83	71
Non-Hispanic black	7	19
Hispanic	3	3
Other	6	7
Education		
High school diploma or less	4	10
Some college to bachelor's degree	49	59
Graduate degree	47	31
BMI (kg/m^2)		
<25.0 (normal-weight)	36	48
25.0–29.9 (overweight)	44	30
≥30.0 (obese)	21	21

AMPM are shown in **Table 4**. Mean EI, as calculated from the mean of the 3 recalls, represented 90% and 88% of the measured TEE for males and females, respectively. Overall, subjects in our study underreported EI by 11% compared with TEE. Raw correlations between TEE and EI were 0.32 for males and 0.25 for females.

The measurements of TEE and REE increased as BMI increased; however, reported EI remained stable, as shown in **Table 5**. Among normal-weight subjects (BMI < 25.0), EI, compared with TEE, was underreported by <1% in males and 6% in females, or <3% overall.

The distribution of EI:TEE is shown in separate graphs for males and females (**Figure 2**). The dotted lines represent the inverse of 95% CI lower and upper limits of the log ratio; points falling between the dotted lines represent AERs, who and are defined as having EI/TEE in the range of 0.72 to 1.40. Points above the dotted lines represent high energy reporters (HERs), and points below the dotted lines represent low energy reporters (LERs).

TABLE 3
Distribution by day of the week for 24-h recalls collected on the total study sample[1]

	Men	Women
	%	%
Weekdays		
Monday	15	13
Tuesday	14	15
Wednesday	16	14
Thursday	14	16
Weekend days		
Friday	14	13
Saturday	13	15
Sunday	15	15

[1] Each subject (*n* = 524) had 3 dietary recalls obtained by using the Automated Multiple-Pass Method over a 2-wk period.

TABLE 4
Daily energy measured in male and female subjects[1]

	Men						Women					
	Subjects	Geometric mean	95% CI	25th Percentile	Median	75th Percentile	Subjects	Geometric mean	95% CI	25th Percentile	Median	75th Percentile
TEE (kcal/d)[2]	249	2861	(2795, 2928)	2542	2877	3196	248	2190	(2140, 2242)	1987	2206	2483
24-h Recall[3]												
1st (kcal/d)	259	2479	(2382, 2580)	2006	2529	3064	258	1933	(1858, 2012)	1596	1989	2399
2nd (kcal/d)	259	2612	(2510, 2719)	2151	2647	3240	257	1938	(1862, 2017)	1593	1948	2444
3rd (kcal/d)	258	2595	(2494, 2701)	2161	2675	3159	259	1908	(1834, 1986)	1517	1948	2357
EI (kcal/d)[4]	260	2561	(2461, 2666)	2201	2629	3004	259	1926	(1851, 2005)	1658	1931	2257
EI/TEE (%)[5]	248	90	(86, 94)	76	89	108	246	88	(84, 92)	73	88	106

[1] TEE, total energy expenditure; EI, energy intake.
[2] Measured by using the doubly labeled water method.
[3] Collected by using the Automated Multiple-Pass Method.
[4] Three-day EI was calculated by using the first, second, and third dietary recalls.
[5] EI/TEE × 100.

TABLE 5
Anthropometric and energy measurements of men and women by BMI category[1]

	Men			Women		
	Normal-weight (*n* = 94)	Overweight (*n* = 114)	Obese (*n* = 54)	Normal-weight (*n* = 127)	Overweight (*n* = 79)	Obese (*n* = 56)
Age (y)	49 ± 11[2]	50 ± 11	52 ± 11	48 ± 11	51 ± 11	49 ± 10
Weight (kg)	72.6 ± 6.86	84.8 ± 6.75	103.7 ± 11.78	59.9 ± 6.11	71.5 ± 6.88	89.0 ± 10.87
Height (cm)	177.4 ± 6.61	176.0 ± 6.75	177.0 ± 6.05	163.5 ± 6.26	162.4 ± 6.63	161.8 ± 7.48
BMI (kg/m^2)	23.1 ± 1.53	27.3 ± 1.49	33.1 ± 3.32	22.4 ± 1.79	27.0 ± 1.33	34.0 ± 3.39
Weight change (kg)[3]	−0.5 ± 0.70	−0.6 ± 0.76	−0.9 ± 0.95	−0.2 ± 0.74	−0.3 ± 0.77	−0.4 ± 0.81
EI (kcal/d)[4]	2593 (2464, 2729)[5]	2545 (2430, 2666)	2541 (2377, 2717)	1953 (1870, 2040)	1884 (1783, 1991)	1928 (1807, 2057)
TEE (kcal/d)[6]	2596 (2506, 2690)	2964 (2869, 3062)	3161 (3014, 3316)	2070 (2007, 2135)	2218 (2134, 2304)	2452 (2338, 2570)
REE (kcal/d)[7]	1587 (1551, 1624)	1767 (1731, 1805)	1928 (1870, 1989)	1321 (1295, 1348)	1398 (1363, 1434)	1551 (1505, 1599)
PAL[8]	1.64 (1.57, 1.70)	1.68 (1.61, 1.74)	1.64 (1.55, 1.74)	1.57 (1.50, 1.61)	1.59 (1.51, 1.66)	1.58 (1.51, 1.69)
EI/TEE (%)[9]	100 (95, 107)	86 (81, 91)	80 (75, 88)	94 (90, 100)	85 (80, 91)	79 (73, 86)

[1] EI, energy intake; TEE, total energy expenditure; REE, resting energy expenditure; PAL, physical activity level. Weight categories by BMI (in kg/m^2) were normal-weight (BMI < 25.0), overweight (BMI 25.0–29.9), and obese (BMI ≥ 30.0).

[2] $\bar{x}$ ± SD (all such values).

[3] Difference in body weight between the start and the end of the 2-wk study period.

[4] Calculated from 3 dietary recalls collected by using the Automated Multiple-Pass Method.

[5] Geometric $\bar{x}$; 95% CI in parentheses (all such values).

[6] Measured by using the doubly labeled water method.

[7] Measured by indirect calorimetry.

[8] PAL = TEE/REE.

[9] EI/TEE × 100.

To permit comparison with studies that use the ratio of reported EI to the estimated basal metabolic rate (EI:BMR), we calculated the corresponding ratio of EI to the measured REE (EI:REE) for the present study. On the basis of a sample mean EI:REE of 1.43 and an average physical activity level of 1.61, an acceptable reporting 95% CI was defined as having EI:REE in the range of 1.15 to 2.25.

Of our subjects, ≈76% were classified as AERs, 20% as LERs, and 5% as HERs (**Table 6**). Although no independent effect was seen with age (data not shown), low energy reporting increased in the higher BMI categories. Among subjects classified as normal-weight, 7% of males and 14% of females were LERs.

DISCUSSION

Validity of the Automated Multiple-Pass Method for assessing energy intake of the group

The utility of the AMPM in assessing EI at the population or group level was supported by the present study, which encompassed a large group of subjects with a BMI range of 18 to 44. Whereas we carefully replicated the NHANES interview procedures, the controlled conditions of the present study may have affected what was eaten and the ability of subjects to recall their food intake. There are some differences between the nature of the self-selected sample used in the present validation study and that used in NHANES, but there is no reason to believe that the accuracy of the recall data from NHANES would be substantially different from that from the subjects used in the present study. However, other demographic characteristics (ie, education and socioeconomic status) may be associated with accurate reporting and would require additional validation with an appropriate sample.

Previously, in a sample of 20 highly motivated, normal-weight women, Blanton et al (12) reported that EI measured by the AMPM did not differ significantly from TEE measured by the DLW or that from 14-d food records. In contrast, mean energy obtained from 2 different food-frequency questionnaires (FFQ) significantly underestimated TEE, by ≈27% on each FFQ. Similar results were reported by Rumpler et al (11) in a sample of 12 normal-weight men; mean EI collected by the AMPM did not differ significantly from measured food intake. However, energy was underreported by 22% on an FFQ in this same sample (27).

In the present study, mean EI was underreported, compared with TEE, by 10% in males and by 12% in females. This degree of underreporting was less than that cited by Subar et al (5) from the OPEN study (*n* = 484), in which, compared with TEE, EI was underreported by 12–14% in males and by 16–20% in females. The smaller degree of energy underreporting in the present study may be due to methodologic advances in the AMPM, to differences in overall study design, or to both. The OPEN study assessed dietary intake from two 24-h recalls collected by using an earlier pencil-and-paper version of the USDA Multiple-Pass Method, and it compared each individual dietary intake to TEE. Our validation study used the AMPM, which automated the entire recall process.

Because previous research has indicated daily biases in food consumption, recalls in the present study were conducted on all 7 d and with an equal distribution of dietary recalls among the 7 days of the week. In addition, interviews for each subject were scheduled so as to capture intake on a weekend day as well as on weekdays. Weekend days are defined as Friday, Saturday, and Sunday, as classified by Haines et al (28), who reported an increase of 115 and 74 kcal/d for weekends over weekdays in adults aged 19–50 and 51–70 y, respectively. In the present sample, the mean EI on weekend days was higher by 190 kcal/d or 13%
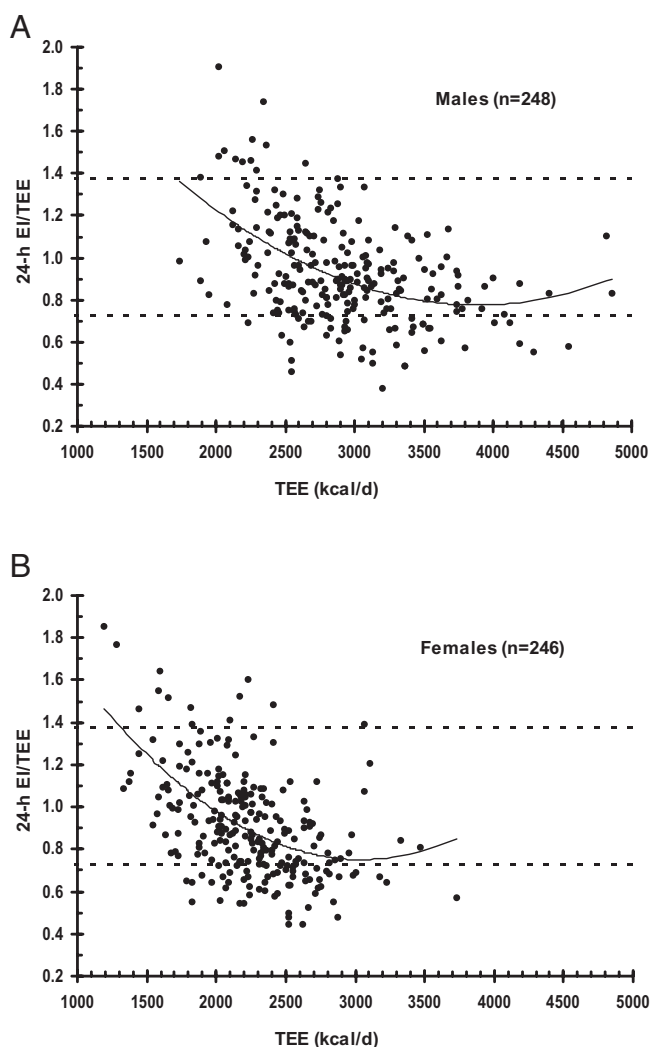
FIGURE 2. Ratio of reported energy intake (EI) to total energy expenditure (TEE) against TEE for men (A) and women (B). The dotted lines represent the inverse of the lower and upper limits of the 95% CI of the log ratio; points falling within the 95% CI range of 0.72, 1.40 represent acceptable energy reporters, points above the upper limit of the 95% CI represent high energy reporters, and points below the lower limit represent low energy reporters. The curved lines represent a quadratic spline fit to the data points. One observation in a female subject outside the x-axes of the plot was excluded.

overall than that on weekdays (29). Given that many Americans are eating more on weekend days than on weekdays, it is imperative that this effect be considered when measuring dietary intake.

Although our first recall was conducted in-person and the second and third recalls were collected via telephone interview, we did not anticipate any inconsistency in reported EIs, because previous research had found 24-h recalls obtained by telephone interview to be as effective as those obtained in-person (30, 31). In addition, a decline in reported EI was not found in the present study by multiple administrations of the AMPM. In contrast, Sawaya et al (32) reported significantly lower EIs in women on a second 24-h recall measurement. Mean intakes in the OPEN study (5) also declined with the second administration of the recall.

Incorporation of the 5-step recall into a computerized method was designed to minimize respondent burden and improve consistency across all interviews. The AMPM includes standardized questions and possible response options, and each option is programmed to proceed to the next appropriate question (1).

Variability at the individual level

Although there was close agreement at the group level, especially in normal-weight subjects, our data show variability in the accuracy of the AMPM at the individual level. Within subjects, the discrepancies between EI and EE also may be due to errors in the DLW method. In a recent validation study (33), TEE measured by DLW on a mean basis accurately estimated TEE observed in a metabolic chamber (1.3 ± 8.9%). However, on an individual basis, the errors ranged from −11.7% to 12.5%. Identification of misreporting of EI at the individual level is also associated with uncertainties due to day-to-day variations in diet. Basiotis et al (34) reported that the average number of days for which records are needed to estimate true average food energy for a person was 27 for males and 35 for females.

With the use of the AMPM, 78% of men and 74% of women were classified as AERs. Despite differences in the agreement between mean EI and TEE, the proportion of AERs is similar to that in the OPEN study (5), which classified 79% of men and 78% of women as AERs. In both studies, subjects were a selected, motivated, and well-educated group, and these characteristics may have influenced their ability to estimate dietary intake. Johnson et al (35) showed higher body fat percentage and low literacy to be the best predictors of EI underreporting in women.

TABLE 6
Percentage of low (LER), acceptable (AER), and high (HER) energy reporters by sex and BMI category[1]

	Men			Women		
	LER (n = 44)	AER (n = 193)	HER (n = 11)	LER (n = 54)	AER (n = 181)	HER (n = 11)
	%			%		
All	17.7 (13.0, 23.0)	77.8 (72.6, 83.0)	4.4 (1.9, 7.0)	22.0 (16.7, 27.2)	73.6 (68.0, 79.1)	4.5 (1.9, 7.1)
Normal-weight	6.7 (1.4, 11.9)	86.7 (79.5, 93.8)	6.7 (1.4, 11.9)	14.4 (8.0, 20.8)	78.8 (71.3, 86.3)	6.8 (2.2, 11.4)
Overweight	19.4 (11.9, 27.0)	77.8 (69.8, 85.8)	2.8 (0.0, 5.9)	24.7 (14.8, 34.5)	71.4 (61.1, 81.8)	3.9 (0.0, 8.3)
Obese	34.0 (20.4, 47.6)	62.0 (48.1, 75.9)	4.0 (0.0, 9.6)	35.3 (21.7, 48.9)	64.7 (51.1, 78.3)	0.0

[1] Weight categories by BMI (in kg/m²) were normal-weight (BMI < 25.0), overweight (BMI 25.0–29.9), and obese (BMI ≥ 30.0). LERs, AERs, and HERs were defined as subjects with values below, within, and above the 95% CI of the log EI/TEE, respectively. AER range = 0.72–1.40.

Comparison with other studies

Because the use of DLW is not practical in large population studies, the prevalence of energy underreporting has been estimated in large dietary surveys by using EI:BMR and by using the cutoffs to identify misreporters, developed by Goldberg et al (36), that vary according to the sample size and the number of days of intake. Using an EI:BMR < 0.9, Briefel et al (37) reported that 18% of men and 28% of women were classified as underreporters in NHANES III, which was conducted in 1988–1994.

On the basis of a summary of 25 studies, Livingstone and Black (13) reported cutoff values for EI:BMR that ranged from <0.9 to <1.28; however, direct comparisons of the degree of underreporting can be problematic because of differences in study design, methods for assessing food intake, and criteria or cutoffs used to identify underreporters (38). When the measured REE value was substituted for BMR, the EI:REE cutoff to define an underreporter in our study was <1.15. Research plans are underway to evaluate the extent of misreporting in WWEIA by using EI:BMR cutoffs and to identify characteristics associated with underreporting.

The accuracy of the AMPM in reporting mean EI within 3% of TEE in our sample of normal-weight persons ($n = 221$) was noteworthy. Just as did previous reports (5, 34, 39–41), we found a greater underestimation of EI with higher BMI classification. It is possible that, on the days when they knew they would have to report what they had eaten, overweight and obese subjects were affected more by the desire to eat less. Although our subjects were not told the exact nature of each interview, all were scheduled in advance, which is similar to NHANES. Over the 2-wk DLW period in the present study, mean body weight decreased in both sexes; weight loss was greatest in the obese groups. This weight loss could be due to protocol differences in fasting conditions between center visits or to a decrease in food consumption during the study period. Goris et al (42) reported a tendency for obese male subjects to reduce their intake and subsequently their body mass when food records were used to assess habitual intake. The tendency for obese subjects to lose weight during a food-recording period has also been reported in women (43).

Conclusions

The AMPM assessed mean EI within 11% of mean TEE in a large sample of normal-weight, overweight, and obese men and women aged 30–69 y. Overall, in normal-weight subjects, EI was underreported by <3%. Further research is needed to determine the psychological and behavioral factors that contribute to the underreporting observed in overweight and obese persons.

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